REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
13-08-2013	Final Report	12-Sep-2012 - 11-Jun-2013

4. TITLE AND SUBTITLE
Final Report

5a. CONTRACT NUMBER
W911NF-12-1-0529

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
611102

6. AUTHORS
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
University of California - Berkeley
Sponsored Projects Office
2150 Shattuck Avenue, suite 300
Berkeley, CA 94704 -5940

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
63092-MA-II.5

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
In this STIR project, we have achieved three major contributions in the application of sparse and low-rank representation in geometric 3D modeling of urban structures and high-dimensional pattern recognition at large. First, we proposed a novel algorithm to effectively detect geometry-rich low-rank image patterns in natural images. Second, we extended a sparse representation-based classification framework to the small-sample-set scenario. Finally, our research on accelerating the speed of sparse optimization solvers was accepted for publication.

15. SUBJECT TERMS
Computer Vision, 3D Model, Low-Rank Representation

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UU	UU	UU	UU		Allen Yang
					19b. TELEPHONE NUMBER
					510-643-5798

Report Title

Final Report

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In this STIR project, we have achieved three major contributions in the application of sparse and low-rank representation in geometric 3D modeling of urban structures and high-dimensional pattern recognition at large. First, we proposed a novel algorithm to effectively detect geometry-rich low-rank image patterns in natural images. Second, we extended a sparse representation-based classification framework to the small-sample-set scenario. Finally, our research on accelerating the speed of sparse optimization solvers was accepted for publication.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
06/30/2013	2.00	Allen Y. Yang, Zihan Zhou, Arvind Ganesh Balasubramanian, S. Shankar Sastry, Yi Ma. Fast l1-Minimization Algorithms for Robust Face Recognition, IEEE Transactions on Image Processing, (08 2013): 0. doi: 10.1109/TIP.2013.2262292

TOTAL: 1

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

1. Henrik Ohlsson, Allen Y. Yang, Roy Dong, and S. Shankar Sastry. Quadratic Basis Pursuit -- A Nonlinear Extension of Compressive Sensing. SPARS Workshop, 2013.

2. Henrik Ohlsson, Yonina Eldar, Allen Y. Yang, and S. Shankar Sastry. Compressive Shift Retrieval. SPARS Workshop, 2013.

Number of Presentations: 2.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

06/30/2013 3.00 Liansheng Zhuang, Allen Y. Yang, Zihan Zhou, S. Shankar Sastry, Yi Ma. Single-Sample Face Recognition with Image Corruption and Misalignment via Sparse Illumination Transfer, IEEE International Conference on Computer Vision and Pattern Recognition. 2013/06/24 03:00:00, . : ,

06/30/2013 4.00 Henrik Ohlsson, Yonina C. Eldar, Allen Y. Yang, S. Shankar Sastry. Compressive Shift Retrieval, ICASSP. 2013/05/27 03:00:00, . : ,

TOTAL: **2**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

1. Method and Apparatus for Single-Image Robust Face Alignment via Illumination Transfer. US Patent Application, 2013.

Patents Awarded

1. Recognition via High-Dimensional Data Classification. US Patent, 2013.

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Chi Pang Lam	0.19	
FTE Equivalent:	**0.19**	
Total Number:	**1**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Ehsan Elhamifar	0.28
FTE Equivalent:	**0.28**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Allen Yang	0.37	
FTE Equivalent:	**0.37**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: ......

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale): ......

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering: ......

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ......

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: ......

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

5 **Method and Apparatus for Single-Image Robust Face Alignment via Illumination Transfer**

Patent Filed in US? (5d-1) Y

Patent Filed in Foreign Countries? (5d-2) N

Was the assignment forwarded to the contracting officer? (5e) N

Foreign Countries of application (5g-2):

5a: Allen Yang

5f-1a: UC Berkeley

5f-c: Cory Hall, Rm 337

Berkeley CA 94720

Scientific Progress

See Attachment

Technology Transfer

1 Statement

In this STIR project, we achieved three major contributions in the application of sparse and low-rank representation in geometric 3D modeling of urban structures and high-dimensional pattern recognition at large.

1. We proposed a novel algorithm to effectively detect geometry-rich low-rank patterns in natural images.
2. We extended a sparse representation-based classification framework to the small-sample-set scenario. We demonstrated the utility of the new technique in a challenging problem of single-sample face recognition.
3. We studied the problem of accelerating sparse optimization solvers. Our results are a set of numerical solvers that have achieved the state-of-the-art performance in both the speed and the accuracy of recovering high-dimensional structured sparse signals.

2 Geometric Segmentation of Natural Images

In the literature of image-based 3D modeling and reconstruction, several types of global or semi-global image features have been recently proposed. In urban-scene modeling, symmetric texture regions are widely used. Using the virtual views of symmetric patterns, their 3D orientation can be readily estimated from just a single image. Another type of geometric features used in 3D modeling are homogeneous color regions such as superpixels whose orientation under perspective projection is consistent with that of some global planar structures in space. Finally, in object recognition and segmentation, various types of object part-based regions that contain rich semantic information have been proposed.

More recently, motivated by the emerging theory of Robust PCA, a new type of invariant feature has been proposed, called *transform-invariant low-rank texture* (TILT). The fundamental idea of TILT is that image texture that represents regular or repetitive 3D shapes in space is often low rank, when the texture region is represented as a matrix of its pixel values. However, under camera perspective distortion and potential pixel corruption, the matrix representation of the texture in the image space exhibits much higher rank compared to its *canonical representation*, i.e., the texture observed under orthographic projection and free of pixel corruption. Therefore, the rank of the texture region can be used as part of an objective function to rectify the underlying image distortion. This new approach suggests that we can obtain accurate geometric models of many urban objects, such as buildings, hallways, road signs, and humans, without relying on extraction of any traditional local features (as shown in Figure 1). More importantly, TILT features can be shown to be robust to camera perspective distortion and can also compensate a moderate amount of pixel corruption, which are the main advantages compared to other existing global invariant features.

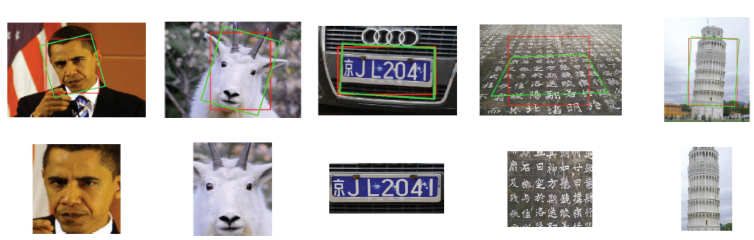

Figure 1: Examples of manually labeled image patterns that are extracted as TILT features. **Top:** Initialization of the feature locations as the red bounding boxes, and the final orientation of the feature as the green bounding boxes. The TILT features compensate the perspective distortion. **Bottom:** Canonical representation of the low-rank matrices.

In this project, we have made notable contributions to extending the utility of TILT features in image segmentation and 3D reconstruction. We have proposed a novel algorithm to effectively recover a top-down hierarchical TILT feature representation in urban images [1]. Compared to traditional image feature detection techniques, Robust PCA is still an very expensive operator applied to high-resolution images. Therefore, naive approaches of using sliding windows, random sampling, or fixed grids are not tractable in finding low-rank texture regions. The algorithm in [1] first utilizes the canonical low-rank matrix representation of image texture and effectively segments urban images into a geometric layer and a non-geometric layer, as shown in Figure 2. In the geometric layer, a multi-scale TILT detection process is applied to further group different scales of TILT features into complexes, each of which represents a more global texture facade that is robust to camera distortion, foreground occlusion, and non-Lambertian texture. The algorithm is also capable of rejecting noisy outlying TILT features. Figure 3 demonstrates some representative results of the multi-scale TILT detection algorithm.

Figure 2: Segmentation of a natural image (left) into a geometric layer (middle) and a non-geometric layer (right).

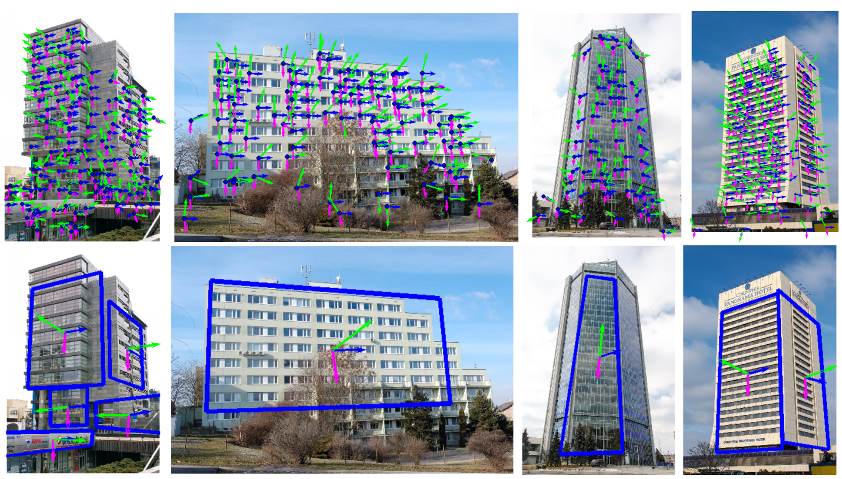

Figure 3: Examples of multi-scale TILT detection (top) and clustering into facades (bottom). The local coordinate frames are superimposed to indicate the estimated surface orientation and the green arrows indicate the normal vectors. The estimation is robust to large perspective distortion, vegetation occlusion, and non-Lambertian surfaces.

3 Single-Sample Face Recognition vis Sparse Illumination Transfer (SIT)

Single-sample face alignment and recognition represents an important step towards practical face recognition solutions using images collected in the wild or on the Internet. We contend that the problem can be solved quite effectively by a simple yet elegant algorithm. The key observation is that one sample per class mainly deprives the algorithm of an illumination subspace model for each individual class. We showed in [2] that a *sparse illumination transfer* (SIT) dictionary can be constructed to compensate the lack of the illumination information in the training set.

Due to the fact that most human faces have similar shapes, only one subject is often sufficient to provide images of different illumination patterns, although adding more subjects may further improve the accuracy. The subject(s) for illumination transfer can be selected outside the set of training subjects for recognition. Finally, we show that the other image nuisances, including pose variation and image corruption, can be readily corrected by a single reference image of *arbitrary illumination condition* per class combined with the SIT dictionary. The SIT dictionary also does not need to know the information of any possible facial corruption for the algorithm to be robust. To the best of our knowledge, this work is the first to propose a solution to perform facial illumination compensation in the alignment stage and illumination and pose transfer in the recognition stage.

In terms of the algorithm complexity, the construction of the SIT dictionary is extremely simple when the illumination data of the SIT subject(s) are provided, and it does not necessarily involve any dictionary learning algorithm. The algorithm is also fast to execute in the alignment and recognition stages compared to the other sparse-representation classifier (SRC)-type algorithms because a sparse optimization solver is now faced with much smaller linear systems.

Our extensive experiments have demonstrated that the new algorithms significantly outperform the existing algorithms in the single-sample regime and with less restrictions. In particular, the face alignment accuracy is comparable to that of the well-known Deformable SRC algorithm using multiple training images; and the face recognition accuracy significantly exceeds those of the Extended SRC algorithms using hand labeled alignment initialization. A comparison on the accuracy of single-sample face recognition via SIT with Deformable SRC (DSRC) and Misalignment Robust Representation (MRR) is shown in Table 1 using the standard Multi-PIE database

Table 1: Single-sample alignment + recognition accuracy on Multi-PIE database.

Method	Session 1 (%)	Session 2 (%)
DSRC	36.1	35.7
MRR	46.2	34.6
SIT	**79.9**	**65.7**

UC Berkeley has filed a US patent application about the new technique.

4 Acceleration of Sparse Optimization Algorithms

In this project, we studied the speed and scalability of sparse optimization algorithms in solving ℓ_1-minimization type problems. Motivated by the emerging compressive sensing theory, the sparsity-seeking property of ℓ_1-min optimization has been shown to have applications in many areas such as geophysics, speech recognition, image compression, processing, and enhancement, sensor networks, and computer vision. In particular, the applications discussed in the previous sections are indeed also examples of sparse optimization problems.

While the ℓ_1-min can be cast as a linear program and readily solved by classical convex optimization methods, their computational complexity is often too high for large-scale, high-dimensional image data. In light of a large number of real applications in compressive sensing, many new efficient algorithms have been proposed over the past decade.

Our first contribution is a novel ℓ_1-min solution based on a classical convex optimization technique known as augmented Lagrangian methods (ALM). In our work [3], we have thoroughly compared the ALM algorithms with several state-of-the-art acceleration techniques for ℓ_1-min problems, which include two classical solutions using interior-point method and Homotopy method, and several first-order methods including proximal-point methods, parallell coordinate descent, approximate message passing, and templates for convex cone solvers (TFOCS).

To concretely demonstrate the performance of ALM and the other algorithms, we have compiled a benchmark using both synthetic data and real high-dimensional image data in face recognition. The ALM algorithms compare favorably among a wide range of state-of-the-art ℓ_1-min algorithms, and more importantly are very suitable for large-scale face recognition and alignment problems in practice. To aid peer evaluation, all algorithms discussed in this work have been made publicly available on our website as a MATLAB toolbox.

References

[1] C. Lam, A. Yang, E. Elhamifar, and S. Sastry. "Geometric Image Segmentation via Multiscale TILT Clustering." *UCB Tech Report EECS-2013-132*, 2013.

[2] L. Zhuang, A. Yang, Z. Zhou, S. Sastry, and Y. Ma. "Single-Sample Face Recognition with Image Corruption and Misalignment via Sparse Illumination Transfer." In *CVPR*, 2013.

[3] A. Yang, Z. Zhou, A. Ganesh, S. Sastry, and Y. Ma. "Fast ℓ_1-Minimization Algorithms for Robust Face Recognition." IEEE Trans. Image Processing, 2013.